REMARKABLE ECLIPSES

A SKETCH OF THE
MOST INTERESTING CIRCUMSTANCES CONNECTED
WITH THE OBSERVATION
OF SOLAR AND LUNAR ECLIPSES,
BOTH IN ANCIENT AND MODERN TIMES

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PREFACE.

THE favourable reception of the former editions of this little work, the first of which was published in 1896, has induced the author to issue a third. Practically, it consists of two parts, though without formal division: a notice of the historical and chronological bearing of eclipses seen before their scientific study began, which may be said to date from the one which was total in England in the year 1715; and a rapid survey of the observations made of those which have occurred since, taken in order, and now including that of January 1898, which was very successfully observed.

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REMARKABLE ECLIPSES.

ECLIPSES of the Sun are of three kinds: total, annular, and partial. The length of the Moon's shadow is about equal to her distance from the Earth; but as that distance varies, owing to the eccentricity of her orbit, the shadow may reach the Earth or may fall a little short of doing so. In the former case, when the Moon passes centrally between the Earth and Sun, the latter will be for a short time (never amounting to quite eight minutes) completely obscured or eclipsed along a line (never more than 170 miles in width), which the Moon's shadow traverses in its course. Over a larger belt on either side of this, part of the Sun will be covered from a spectator located therein, and there will be a *partial* eclipse. But if the Moon, at the time of coming centrally between the Earth and Sun, is at or near the part of her orbit where she is farthest from us, her shadow will not reach the Earth, but in places on the central line

along a zone of very narrow width, she will be seen on the Sun apparently not large enough to cover it, but leaving a ring (Lat. *annulus*) of bright sunlight all round her dark disc: this is called an annular eclipse. Outside this narrow zone, on either side of it, as in the case of a total eclipse, there will be a partial eclipse. Some eclipses, of course, are only partial, on account of the Moon's shadow falling above or below the Earth, so that only a portion, greater or smaller, of the Sun is obscured at any place.

The eccentricity of the Moon's orbit is the principal cause of the differences above spoken of with regard to a central eclipse being total or annular. But the eccentricity of the Earth's orbit and the position in it at which the Earth (and attendant Moon) is situated at the time of the eclipse, has some effect upon this and upon the length of time which the eclipse, if total, lasts as such. The diameter of the Sun is about 866,000 miles; his mean distance from us is nearly 93,000,000 miles, but this varies between about 91,500,000 and 94,500,000, the difference being 3,000,000, or about the thirtieth part of the whole. The diameter of the Moon is about 2160 miles. Her distance from the Earth varies between

253,000 and 221,600 miles; the difference being 31,400 miles, nearly an eighth part of the whole.

That which renders total eclipses of the Sun peculiarly interesting in a scientific point of view is that the extinction of his light by the interposition of the Moon enables us to see masses of matter surrounding him, the comparatively feeble light of which is at other times overpowered by his brilliancy. The study and investigation of these has formed one of the most interesting problems in astronomy since special attention was first directed to them on the occasion of the great total eclipse seen in Southern Europe in 1842. But before entering on that and later eclipses, we propose to give a brief survey of the most remarkable eclipses recorded in history, some of which have helped to throw light upon disputed questions in chronology, as we are able to compute the dates of these and to compare them with the accounts related by historians; that is, when these are sufficiently precise to make identification of the calculated and observed phenomena possible.

The ancient Egyptian records have hitherto furnished no instance in which this could be done with any probability; and though inge-

nious attempts have been made to identify a few alluded to in the Rig-Veda, it cannot be said that these have been very successful. The earliest mention of a solar eclipse of which the actual date can be fixed with a high degree of probability is to be found in the Chinese annals. It appears to have taken place in the year corresponding to B.C. 776—that which, by a remarkable coincidence, was the first of the 1st Greek Olympiad. The record is found in the 'She-King,' a series of poetical works collected by one of the disciples of Confucius, and the writer expresses his dread of a phenomenon (of a far more terrible kind, he thinks, than an eclipse of the Moon) which presaged the disruption of all proper government. It appears very probable that the eclipse was one shown by calculation to have taken place on the 6th of September in the above year.

The Assyrian tablets record three eclipses of the Sun, one of which appears to have been total in or near Nineveh. This occurred on the 15th of June in the year B.C. 763, and is mentioned in the so-called Assyrian 'Eponym-Canon,' which was interpreted by the late Sir Henry Rawlinson in 1862 from the fragments of terra-cotta tablets brought over by Layard and placed in the British Museum. The in-

scription in question (as kindly translated for the author by Mr. T. G. Pinches, of the British Museum) states that "in the Eponymy of Bursagale, Governor of Gozan, a revolt in Assur [i.e. the city] took place in the month Sivan, and the Sun was eclipsed." This, according to the Canon, was in the eighth year of the reign of Assur-day-an, and the record must be allowed to fix subsequent dates in the Canon with great precision. Another eclipse is mentioned on a tablet in the reign of Esar-haddon, the son and successor of Sennacherib, which would seem to be one calculated to have occurred on the 27th of May, B.C. 669; it was only partial in Assyria, but was annular farther to the east. A large partial eclipse seems also to be referred to in an inscription eight years afterwards in the reign of Assur-banipal; it is rather difficult to explain all its circumstances, as a darkness for three days is spoken of in the evening; but Mr. Pinches thinks that this is intended for a separate occurrence from the eclipse, which was probably that of the 27th of June, B.C. 661.

We now come to a very interesting eclipse. Herodotus states that in the sixth year of the war between Alyattes, King of Lydia, and Cyaxares, King of Media, just when a battle

was about to take place, day was suddenly changed into night, which led to a termination of the contest; he adds that this eclipse (that is, the year in which it was to take place) had been foretold by Thales, who, whether this be true or not, was certainly the first Greek astronomer. There has been much discussion with regard to the date of this eclipse; but a full consideration of all the circumstances leads to the very probable conclusion that it was the total one of the 28th of May, B.C. 585, which was very large in Asia Minor towards sunset. As the war between the Lydians and Medes began some years after the destruction of Nineveh by the combined armies of Cyaxares and Nabopolassar of Babylon (the father of Nebuchadnezzar), this helps approximately to determine the general chronology of those times.

The next important ancient statement of the occurrence of a solar eclipse has given even more trouble to historians than the above, in a different way. Herodotus says that when Xerxes was setting out from Sardis for Abydos on his famous Grecian expedition, "at the moment of departure, the Sun suddenly quitted his seat in the heavens and disappeared, though there were no clouds in

sight, but the sky was clear and serene." Now, there can scarcely be any doubt, from the whole course of Grecian history and its successive events, that the year when this took place and in which the battles of Thermopylæ and Salamis were fought, was B.C. 480. No eclipse of the Sun, it is known by calculation, occurred in the spring of that year. Some have therefore proposed to remove the date to one year earlier, as an eclipse took place on the 19th of April in B.C. 481 ; but not to mention other objections, this is little consistent with the historian's statement that the season was "on the first approach of spring." The late Astronomer Royal (Sir George Airy), on the other hand, suggested that Herodotus wrote an eclipse of the Sun instead of one of the Moon, as an eclipse of the latter occurred on the early morning of March 14th, B.C. 479, thus making the date one year later instead of earlier. We may put aside all suggestions of any date still further removed from that accepted, which there is no sufficient reason for altering. That B.C. 480 was the true date is confirmed by the statement of the same historian that an eclipse of the Sun took place later in the same year, which so frightened Cleombrotus,

King of Sparta (brother of Leonidas, who fell at Thermopylæ), whilst he was occupied in fortifying the Corinthian isthmus, that he hastily returned home with his men. This appears to have occurred in the autumn, and must have been the one, very large and annular in some places, which is calculated to have taken place on the 2nd of October, B.C. 480. How then shall we explain the extraordinary darkness when the Persian army was leaving Sardis in the spring? Possibly it may have been caused by a remarkable atmospheric phenomenon; or we may accept Prof. Rawlinson's suggestion that "Herodotus may perhaps have understood of the setting forth from Sardis what was told him of the departure from Susa in the spring of the preceding year," when, as we have said, an eclipse did occur in April, and the historian may have been mistaken with regard to the exact time of the year. It should be recollected that a total or very large eclipse seen at Sardis would also have been visible in Greece; but this would not apply to Susa.

The next eclipse of the Sun which is of historic interest took place in the first year of the Peloponnesian war, and fixes its date to B.C. 431, as calculation shows that a total

eclipse occurred on the 3rd of August in that year. Plutarch relates an amusing anecdote with regard to it; that the pilot of a ship in which Pericles was about to sail for the Peloponnesus was much alarmed at the phenomenon, and Pericles reassured him by holding his cloak before his eyes and telling him that the only difference between that and the eclipse was that something larger than the cloak prevented his seeing the Sun for a while. A large eclipse is also recorded by Thucydides to have taken place in the eighth year of the Peloponnesian war; this (which was not total) fell on the 21st of March in the year B.C. 424.

We are also indebted to Xenophon for the mention of two eclipses of the Sun. One of these (very large in Greece, and annular farther north) took place on the 3rd of September, B.C. 404, the year in the spring of which Lysander had taken Athens and closed the first Peloponnesian war, after a duration of almost exactly twenty-seven years. The other occurred ten years later, on the 14th of August, B.C. 394, just when the news of the naval victory of Conon, in alliance with the Persians, over the Lacedæmonian fleet off Cnidus in Caria, reached Agesilaus as he

was entering Bœotia, and induced him to force on the battle of Coroneia before the enemy should hear of the Spartan defeat at Cnidus.

The next solar eclipse of great interest in an historical point of view is that commonly known as the eclipse of Agathocles, which is mentioned by Diodorus Siculus and Justin. Whilst Agathocles was blockaded in Syracuse by the Carthaginian fleet, he formed the design of eluding them and invading their territories in Africa, which he succeeded in doing whilst they were attacking a convoy of provision-ships, and then escaped in the darkness of night. Next day "there was such an eclipse of the Sun that the day wholly put on the appearance of night, and the stars were seen in all parts of the sky." The eclipse was evidently the total one of the 15th of August, B.C. 310. I need not enter into its details, of which Airy and others have treated fully. It determines the date of the expedition without any doubt and with great accuracy.

We have now to speak of a few solar eclipses referred to in Roman history. The first of these which is connected with any historical event occurred on the 11th of February in the year B.C. 217, and is men-

tioned by Livy as happening in the second year of Hannibal's campaigns in Italy, and not long before his victory over Flaminius at the Lake Trasimenus; it was total in northern Africa in the afternoon, passing in a north-easterly direction from near Cape Verde to the eastern Mediterranean, between the islands of Crete and Cyprus, so that it was a large partial eclipse in Italy. Another (a comparatively small one) occurred on the 19th of October, in the year B.C. 202, about a month before the battle of Zama, in which Scipio defeated Hannibal in Africa, and thus put an end to the second Punic War. Some modern writers erroneously connect the battle with the eclipse.

It is difficult to trace the source of an erroneous statement which has often been made, that an eclipse of the sun took place when Julius Cæsar crossed the Rubicon. The exact date of this event is not known, but it was probably about the end of the year B.C. 50. An eclipse (annular in some places) took place on the 9th of August in the following year (B.C. 49), and is mentioned by Dion Cassius in connexion with Pompey at Dyrrachium, just a year before the battle of Pharsalia.

Of the eclipses which took place after the Christian era, the first to be mentioned is one stated by Phlegon to have occurred in the eighteenth year of the reign of Tiberius, doubtless that calculated to have been total in Asia Minor on the 24th of November, A.D. 29, a few months before the Crucifixion of our Lord. Another is mentioned by Tacitus as having occurred in the year in which Agrippina was murdered by her son, the Emperor Nero, which corresponds to A.D. 59; the date of this eclipse was April 30.

One also took place in A.D. 71, the first year of the reign of Vespasian, on the 20th of March. But we now come to a time when reference is first made to a phenomenon, the study of which forms in our days the chief scientific interest of a total eclipse of the Sun; we refer, of course, to the so-called corona, which is only fully manifested on these occasions, though it is also less distinctly seen in annular and large partial eclipses, and there seems reason to think that in ancient times it may have been stronger and occasionally visible when there was no eclipse at all.* But

* See a letter by the author in 'The Observatory,' vol. ix. p. 129 (March 1886) in reference to a passage in Philostratus.

it is thought that the earliest mention of it is by Plutarch, in chapter xix. of his treatise 'On the Face appearing in the Orb of the Moon.' Speaking of what is seen during a solar eclipse (probably the one, then recent, in A.D. 71, just mentioned), he says that the obscuration by the Moon "has no time to last and no extensiveness, but some light shows itself round the Sun's circumference, which does not allow the darkness to become deep and complete." This *may* be a reference to what was in later times called the corona; but no further mention of it was made until nearly the end of the sixteenth century. On the 25th of February, O.S. (March 7, N.S.), 1598, an eclipse was total over Scotland and part of North Germany; a Hungarian physician named Jessensky (his name was Latinised by Kepler into Jessenius) observed this at Torgau, and noticed a bright light round the Moon at the time of totality. A similar appearance was remarked at an eclipse which was total for a very short time at Naples on the 12th of October (N.S.), 1605. But the first person who gave anything like a detailed description of it was Dr. Wybord on the occasion of a total eclipse observed by him at Carrickfergus in the north of Ireland, on the 29th of

March (which would be the 8th of April by New Style), 1652. He states that when the Sun was totally eclipsed, a corona of light appeared round the Moon, arising from some unknown cause, and having a uniform breadth of nearly half a digit (which would be nearly three minutes of arc); this emitted a bright and radiating light, and appeared concentric with the Sun and Moon when the two bodies were in conjunction.

Before we proceed to modern observations, which have imparted so high a scientific interest to these and other appearances seen during total and nearly total eclipses of the Sun, we shall mention a few more of which the interest is only chronological and historical. One occurred on the 5th of August, A.D. 240, early in the reign of the young Emperor Gordian III. The mention of one by Idatius as having occurred in the eighth year of the reign of Arcadius and Honorius, and our knowledge that it took place on the 11th of November, A.D. 402, fixes the date A.D. 395 as that of the death of the Emperor Theodosius the Great, the last who ruled the united Roman world.

An eclipse is recorded to have taken place on the 19th of July, A.D. 418, and is remarkable for the fact that a comet was then

noticed which had not been previously seen, though it was afterwards followed during four months. Philostorgius, the ecclesiastical historian, says that some people ignorantly mistook the phenomenon for a comet, with which, he says, neither its appearance nor motion agreed; but it is difficult to see what else it could have been, whilst the critic evidently knew no more of astronomy than those whom he thus censures. The eclipse was very large at Constantinople, and total further to the south. A total eclipse was also seen in north-western Europe in the year A.D. 485, on the 29th of May.

The first solar eclipse recorded to have been seen in this country, took place on the 15th of February, A.D. 538, and is mentioned in the Anglo-Saxon Chronicle. It was four years after the death of Cerdic, the first king of the West-Saxons. About two-thirds of the Sun's disc seems to have been eclipsed at London. Another, annular in some parts of England, occurred on the 14th of August, in the year A.D. 733, and is also mentioned in the Chronicle as being the year in which Ethelbald, king of Mercia, took Somerton. A total one took place in A.D. 878 (the year of King Alfred's great victory over the Danes in Wilt-

shire) on the 29th of October; the Chronicle, by some inadvertence, speaks of an eclipse in the following year, A.D. 879, when none occurred, so that it means either this or the annular one of March 14, A.D. 880. A more remarkable error is made under A.D. 1135, for the death of Henry I. that year is confounded with his leaving England and passing over into Normandy for the last time two years before, in A.D. 1133, when a very large eclipse occurred on the 2nd of August. William of Malmesbury says that this was on the day after Lammas, when the king was passing the Channel on his last voyage.

The year A.D. 1140 was remarkable for the last total solar eclipse visible in England for several centuries. Indeed, there have been none since, except those of 1715 and 1724, up to the present time. That of 1140 took place on the 20th of March. The Saxon Chronicle says of it, "In Lent the Sun darkened about the noon-tide of the day, when men were eating; and they lighted candles to eat by. . . . Men were very much struck with wonder."

There is no occasion to mention all the succeeding accounts of eclipses until they become of scientific interest. But it may

amuse, as a remarkable instance of how blunders are sometimes made by merely mistaking words, just to refer to the statement of several historians, that a "fearful eclipse" took place on the morning of the battle of Crécy. Now, it was fought on the 26th of August, A.D. 1346, about a week after the New Moon, so that no eclipse could have happened; as a matter of fact, no solar eclipse was visible in Europe during the year. The source of the mistake was pointed out by Sir George Cornewall Lewis in 1863, only a short time before his death on the 13th of April in that year. Froissart, in describing the battle, uses the old French word *esclistre*, which means lightning, but was erroneously taken to mean eclipse; the storm was "moult [an obsolete French word, derived from *multum*, of which Littré regretted the loss] grand et moult horrible"; hence the epithet "fearful" applied to the supposed eclipse, which had no real existence.

We will now pass on to the notices of those phenomena which have in our days rendered solar eclipses of such very great interest. The first of these was in reference to one which was total in Switzerland on the 12th of May, 1706, and was observed by Captain Stannyan

at Berne. As this is probably the first mention of the phenomena which became so famous in later times, under the designation of red flames or rose-coloured protuberances, it may be well to quote his exact words, in which, in a letter to Flamsteed, he says that the Sun's "getting out of his eclipse was preceded by a blood-red streak of light from its left limb, which continued not longer than 6 or 7 seconds of time; then part of the Sun's disc appeared all of a sudden, as bright as Venus was ever seen in the night, nay brighter; and in that very instant gave a Light and Shadow to things as strong as Moon-light uses to do." On this Flamsteed remarks:—"The Captain is the first man I ever heard of that took notice of a Red Streak of Light preceding the Emersion of the Sun's body from a total Eclipse. And I take notice of it to you [i. e. the Royal Society] because it infers that *the Moon has an atmosphere;* and its short continuance of only six or seven Seconds of time, tells us that *its height is not more than the five or six hundredth part of her diameter.*"

Very different, we now know, was the true significance of those remarkable phenomena, so startling when first observed; but it was long a subject of discussion whether they

appertained to the Sun or the Moon. But, before leaving the eclipse of 1706, reference should be made to some observations made by M. Fatio de Duillier,* who was located at Geneva, and describes the appearance of what is now technically called the Sun's corona. After speaking of a narrow whiteness (he did not notice the red streak in this, seen by Captain Stannyan) he says that the Moon "did appear very black, and her Disk very well-defined, within the Whiteness, which encompassed it about, and whose Colour was the same with that of a White Crown or *Halo*, of about four or five Degrees of Diameter, which accompanied it, and had the Moon for its Center." Two observers at Montpellier give a similar description.

The next great eclipse was total in London and its neighbourhood in the year 1715, on the 22nd of April, O.S. (May 2nd, N.S.). Halley (then secretary of the Royal Society) had made very elaborate preparations for making full use of the phenomenon, and observed it himself at the Society's apartments in Crane Court. Both the luminous ring or corona and the red flashes or streaks were noticed. Although he considered that the ring was due to

* He was long resident in England, and died near Worcester in 1753, aged 89.

a lunar atmosphere, he was astonished at the great height to which it (on that supposition) extended; and was afterwards struck by the remarks of some other careful observers, that the breadth of the ring increased on the west side of the Moon as the emersion approached.

This would indicate that its parts were successively covered by the Moon as she advanced, and show, if proved, that the phenomena did not appertain to her. Halley, however, did not feel confident on this point. But with regard to the appearances nearer the Moon's dark disc, he says, "I found that there were perpetual Flashes or Coruscations of Light, which seemed for a Moment to dart out from behind the Moon, now here, now there, on all Sides, but more especially on the Western Side, a little before the Emersion: And about two or three Seconds before it, on the same Western Side where the Sun was just coming out, a long and very narrow Streak of a dusky but strong Red Light seemed to colour the dark Edge of the Moon, tho' nothing like it had been seen immediately after the Immersion. But this instantly vanished upon the first Appearance of the Sun, as did also the aforesaid luminous Ring."

We have said that several persons thought that the luminous ring or corona (as it is now universally called) was successively covered and uncovered by the motion of the Moon. This, however, was not the opinion of M. Louville, of the French Academy of Sciences, who had come to London expressly to observe this eclipse, and who thought that the Ring was exactly concentric with the Moon. He saw a bright red circle encompassing the Moon, whilst projected on the Sun; and we now know that the red flames or protuberances are, in fact, only special and higher parts, produced by upward rushes of tremendous velocity in the gaseous envelope surrounding the definite boundary of what is called the Sun's photosphere. We will here anticipate, and state that this gaseous envelope has acquired in our time the name chromosphere, which cannot now be dislodged, though chromatosphere would have been more correct.

The total eclipse of 1715 was succeeded by one nine years afterwards, in 1724, on the 11th O.S. (22nd N.S.), of May. This, although total in some parts of England, appears, chiefly on account of the unfavourableness of the weather, to have been seen there only by one

person, Dr. Stukeley, from the summit of Haradon Hill, near Salisbury. (He had observed the eclipse of 1715 from the steeple of Boston Church, Lincolnshire.) But it was well seen in France; and Maraldi noticed that at its commencement the luminous ring was wider on the eastern side of the Moon than on the western, whilst towards the end it was the reverse, wider on the western than on the eastern. He noticed also that the breadth on the northern limb exceeded that on the southern, so that the ring was at no time exactly concentric with the Moon.

But before quitting the eclipse of A.D. 1715, we should have mentioned another circumstance (one of the many noticed by Halley), i.e., the first account of the appearance which more than a century afterwards acquired the name of Baily's Beads, as will be stated in its proper place. Halley's remark is that "about two Minutes before the Total Immersion, the remaining part of the Sun was reduced to a very fine Horn, whose Extremities seemed to lose their Acuteness, and to become round like Stars." An annular eclipse passed over Scotland on the 18th (29th, N.S.) of February, 1737; on this Maclaurin, who observed it at Edinburgh, informs us that most of the tele-

scopic observers "mention in their Letters, that as the *Annulus* was forming, they perceived the Light to break in several irregular Spots near the Point of Contact, and that the Limb of the Moon seemed to be indented there;" and he adds that, at the dissolution of the annulus, "the Irregularities of the Moon's Surface occasioned the same Appearances, in some measure, as at its Formation."

The eclipse of the 14th (25th, N.S.) of July, 1748, was also annular over a part of Scotland; it was seen, amongst others, by M. Le Monnier, who had come over from France for the purpose and observed it at Aberdour Castle, about ten miles north-west of Edinburgh; but it cannot be said that any additions were made on that occasion to the knowledge of the special phenomena, except that Short speaks of a brown light (evidently that of what is now known as the chromosphere, from its deeper colour during total eclipses), being plainly observed to proceed or stretch along the circumference of the Moon.

The next eclipse which calls for special notice is one which was total in southern Europe on the 24th of June, 1778. The hero of this was Don Antonio de Ulloa, whose career was somewhat remarkable. Sent by

the Spanish Government to South America in 1735 for geodetical operations in Peru, he returned to Europe in 1746, was taken prisoner by an English ship, and brought to London, where he was immediately released, and soon afterwards elected a Fellow of the Royal Society. In 1766 he was appointed Governor of Louisiana, a post which he held for only a short time. From 1770 to 1780 he was in command of a naval squadron, and it was whilst thus acting as an admiral that he observed the eclipse in question, being at the time on board the *Espagne*, and sailing from the Azores to Cape St. Vincent, where he landed on June 29, five days after the eclipse. His account of the phenomenon is given (both in French and English) in vol. lxix. of the 'Philosophical Transactions.' In several respects he expresses his regret that the observation being made on shipboard precluded the determination of measures which might have been useful; but his description of the corona or luminous ring (as he calls it) is very interesting. The totality lasted about four minutes, from 16 to 12 minutes before 4 o'clock in the afternoon. "Five or six seconds," he says, "after the immersion, we began to observe round the Moon a very brilliant circle

of light, which seemed to have a rapid circular motion, something similar to that of a rocket turning about its center. This light became livelier and more dazzling in proportion as the center of the Moon approached to that of the Sun, and about the middle of the eclipse it was of the breadth of about a sixth of the Moon's diameter. Out of this luminous circle there issued forth rays of light, which reached to the distance of a diameter of the Moon, sometimes more, sometimes less, which made one think that they were parts of a weaker light which were reflected in an atmosphere more subtle than that in which the ring was formed. . . . . The colour of the light was not the same everywhere ; the part immediately joining the disk of the Moon was of a reddish cast; from thence it changed towards a pale yellow, which about the middle began to clear, till, at the external extremity, it ended in an almost entire white. It was equally brilliant throughout, and the whirling motion, common to all the parts of it, seemed to change the form and position of the rays, which appeared to the eye sometimes longer, sometimes shorter, at the same time that there was no change either in the colours of the ring, or their arrangement." Ulloa held the

older and now long since quite exploded notion that the luminous ring or corona was the effect of the Sun shining through a lunar atmosphere. But one of the most interesting of his observations (confirmed by those of two of his officers) was what he calls a small point of the Sun like a star on the edge of the Moon; it was of a fiery red colour (equalling, when brightest, a star of the second magnitude), and visible during about a minute and a quarter, disappearing when totality ceased. His theory of it was that it was occasioned by a portion of the Sun's light seen through a crevice or irregularity in the Moon's limb, and it was long spoken of as Ulloa's hole (*trou d'Ulloa*), but there is no doubt that the appearance was really that of a large and brilliant protuberance or prominence in the Sun's chromosphere. As the late Mr. Ranyard remarks, "The indentations or notches beneath prominences spoken of by so many observers, are, it can hardly be doubted, due to irradiation which causes the brilliant prominences to seem larger than they really are, and consequently to appear to overlap the limb of the dark Moon."*

* 'Memoirs of the Royal Astronomical Society,' vol. xli. p. 231.

A total eclipse of the Sun was observed in America on the 27th of October, 1780, an annular one on the 3rd of April, 1791, and another total on the 16th of June, 1806. Bowditch, who observed this last at Salem, says that "the whole of the Moon was then seen surrounded by a luminous appearance of considerable extent." But noteworthy was the remark of Don José Joaquin de Ferrer, who observed the same eclipse at Kinderhook, in the State of New York. If the luminous ring, he argued, was due to a lunar atmosphere, it would follow that this must have a height fifty times as great as that of the Earth's; to state which is to see its absurdity, and therefore he concluded that the appearance in question appertained not to the Moon, but to the Sun.

It was on the occasion of the eclipse which was annular in the south of Scotland and the north of England, on the 13th of May, 1836, that Baily (who observed it at Inch Bonney, near Jedburgh) gave that elaborate description of the appearance of the part of the Moon's circumference just entering on or passing off the Sun's disc, which has since acquired the name of "Baily's Beads," though (as we have said) it had been noticed long before. He

was especially struck by the suddenness of the formation (almost as if caused by the ignition of a fine train of gunpowder) of the row of "lucid points, like a string of bright beads, irregular in size and distance from each other."

It is, however (as Prof. Todd, of Amherst College, remarks in the Preface to Mrs. Todd's valuable little book on 'Total Eclipses of the Sun'), from the great eclipse of 1842 that we must date the dawn of a golden age of physical research upon the Sun. That eclipse occurred on the morning of the 8th of July, and was central and total over a large part of Southern Europe. To witness it, Airy, then Astronomer Royal, left the Greenwich watch-towers, and proceeded to Turin; Arago, Director of the Paris Observatory, repaired to Perpignan (near which he had been born); Baily went to Pavia; and many other astronomers of different nationalities occupied (as the expression now is) various points on the line of totality. Sir John Herschel was at Milan, and describes, in a letter to his aunt, the shouts raised by the crowd at the sudden darkness caused by the eclipse, and the appearance of the Sun when wholly covered by the Moon.

Baily, by the side of his telescope in an upper room of the University of Pavia, speaks of being "astounded by a tremendous burst of applause from the streets below, and at the same moment electrified at the sight of one of the most brilliant and splendid phenomena that can well be imagined," referring to the sudden appearance of the corona in all its glory. The breadth, estimated from the Moon's circumference, was nearly equal to half her diameter. He was also struck by the appearance of three large protuberances, of a roseate cast of colour and somewhat resembling the snowy tops of the Alpine mountains when coloured by the rising or setting Sun. These were also well seen by the other observers, Airy comparing them in shape to the teeth of a circular saw. The appearance and extent of the corona were very different as seen from different places, influenced, doubtless, both by atmospheric conditions and the apparent elevation of the Sun in the sky; Struve, who observed at Lipetzk, in Southern Russia, estimating it as many times larger than those did who saw it from Italy.

If the south of Europe attracted astronomers in 1842, the north did quite as much in 1851. For on the 28th of July in that year, the line

of centrality of a large total eclipse passed over a portion of Sweden and Norway. It was on this occasion that it was recognised that the rose-coloured protuberances were, in fact, produced by upward rushes of gaseous matter from a continuous envelope round the Sun, to which Airy applied the term "sierra"; also, that they were clearly covered and then uncovered by the dark body of the Moon in her advance, proving conclusively that they were solar manifestations.

An annular eclipse passed over England, from Lyme Regis, in Dorsetshire, to the Wash, between Norfolk and Lincolnshire, on the 15th of March, 1858. We need not delay to speak of this, but will pass on to the total eclipse of 1860, which took place on the 18th of July and passed across Spain. It is especially remarkable as being the occasion of the first application, in the hands of De la Rue and Secchi, of photography to the observation of eclipses and the solution of the problems presented by them. The result was that the red flames or prominences were found to present the same appearances at localities far distant from each other, whilst photographs taken at successive stages of the eclipse proved beyond the possibility of doubt that

the Moon gradually passed over them, and that they, as well as the corona, were appendages of the Sun.

Spectroscopy was now putting forth its claim as a new and powerful engine in astronomical research. A fine total eclipse (totality to last nearly six minutes) had been predicted for the 18th of August, 1868, but for its effectual observation it was necessary to repair to India. English and French spectroscopists were there. The appearance of bright lines in the spectrum at once indicated that the protuberances and the sierra or layer from which they arose were composed of glowing vapours, amongst which it was not difficult to recognise the characteristic light of hydrogen. But was it not possible to give more continuous study to these than could be obtained during the few minutes' duration of a total eclipse? Struck by the brilliancy of the lines in the spectrum at this Indian eclipse, M. Janssen (who, like Major, now General, Tennant, observed it at Guntoor) exclaimed, "Je verrai ces lignes-là en dehors des éclipses!" Of course, it is obvious that the solar appendages are always there, though they had hitherto only been seen (except doubfully) during total or annular eclipses; just as we know the stars

are as much present by day as by night, though the far-surpassing brightness of the daylight precludes their visibility, with the occasional exception of Venus when exceptionally bright (particularly in winter), and that a few of the most brilliant stars can be seen through a good telescope. So the glare of the great luminary, with its atmospheric dispersion, ordinarily deprives us of the sight of his beautiful surroundings, the existence of which is clearly manifested and excites such admiration when a total eclipse occurs. But the little eye of a spectroscopic slit offered a hopeful means of bringing part of these, or, at any rate, of their effects, into view without an eclipse. Indeed, the monochromatic light which forms the bright lines in the spectrum especially admits of showing itself above the continuous light when this is sufficiently dispersed. On the morning following the eclipse, and during several subsequent days, M. Janssen succeeded in this way in obtaining evidence of the violent and rapid changes in progress in the gaseous upward rushes from the chromosphere—as it began to be called about this time. During the eclipse of which we have just been speaking, a huge spiral structure, at least 89,000 miles high, was per-

ceived, formed, as Major Tennant concluded from its appearance on his photographs, by the encounter of two mountain torrents of flame. Next morning, M. Janssen found that, like the baseless fabric of a vision, it had so passed away that scarcely a trace remained to show where it had been. But the great French physicist was not alone in his discovery of the means of thus studying the protuberances and their changes without an eclipse. Prof. (now Sir) Norman Lockyer had for some time conceived the idea that these might be seen by the aid of a special kind of spectroscope which he had ordered to be constructed for the purpose. Delays in its completion unfortunately prevented experiments with its use until the 20th of October, 1868; and so it came about that his report of his success reached the French Academy a few minutes only before the despatch of M. Janssen communicating his observations in this way. The principle had also occurred to Dr. (now Sir William) Huggins early in the same year, though his success in its application dates after that of Janssen and Lockyer. To the latter, we should remark, is due the appellation of chromosphere, by which the solar envelope is called, from which the red flames or protuberances proceed.

The next year after the Indian eclipse, on the 7th of August, 1869, one occurred in North America, which passed diagonally across the United States from Behring's Straits to the coast of North Carolina. This was remarkable for the discoveries made in the spectrum of the corona, the full significance of which was not apparent until long afterwards. Nearly at the end of the following year, on the 22nd of December, 1870, an eclipse was total for little more than two minutes over part of the Mediterranean and its shores. M. Janssen escaped out of Paris (then surrounded by German armies) in a balloon, and went to Oran to see this eclipse, but his hopes were defeated by the cloudy weather. An English party on the same occasion suffered shipwreck on the coast of Sicily, and were not able to do anything effective. But the eclipse will ever be remarkable for Prof. Young's (of Princeton, New Jersey) first perception of the reversal of the lines (bright for dark) in the solar spectrum. Very nearly a year after this eclipse, on the 12th of December, 1871, an eclipse was total in Southern India and in Australia. Janssen, Lockyer, Tennant, Colonel Herschel and several others observed this, which fully

proved a large part of the corona to consist of reflected sunlight (confirming the evidence obtained by the polariscope), and also that it contained hydrogen far above the region to which the prominences extend.

No other eclipse of importance for the study of solar physics occurred till 1878, on the 29th of July, and this conferred its greatest favours on the western States of North America. The corona was much smaller and less brilliant than in the last-mentioned eclipses. It is impossible to avoid connecting this with the fact that 1871 was an epoch of sun-spot maximum, whereas these phenomena were nearly at a minimum in 1878. Still very interesting observations of its form were made ; and specially interesting were the results obtained by viewing it from great elevations in the Rocky Mountains, Prof. Langley in particular observing it from the summit of Pike's Peak, 14,100 feet above the level of the sea. In this situation the corona remained perceptible until more than four minutes after totality had ceased. Previous results as to its composition were confirmed.

Nearly four years more passed away. On the 17th May, 1882, an eclipse was total in

Upper Egypt for little more than a minute, an interval which, however, was fully utilised. We were now almost at a sun-spot maximum, and the appearance of the corona strongly resembled that noticed in 1871, the previous epoch of maximum. Valuable additional observations were made by the application of the photographic camera and the spectroscope to this marvellous solar appendage, the resemblance of which to the zodiacal light had before been recognised, suggesting a community of origin. But a very remarkable circumstance attended this eclipse which must not be passed over. One of Dr. Schuster's photographs, taken at Sohag, depicted a bright comet near the outer limit of the corona, which was rendered momentarily visible by the eclipse, but not seen before or since.

As we mentioned in the former part of this little treatise, one was seen first during a total eclipse in A.D. 418, but that was also observed for several months afterwards, whereas the comet of 1882 only manifested its existence by being registered on a photographic plate whilst the Sun was totally obscured. It was after this eclipse that Dr. Huggins conceived the idea that a part of the corona might be

photographed without an eclipse. But it can hardly be said that unequivocal success has yet been obtained in this; and it has been thought that the effects of the volcanic explosion in the Straits of Sunda in the month of August 1883 (which produced those remarkable coloured sunrises and sunsets, lasting a long time afterwards) prevented during two or three years delicate observations in the vicinity of the Sun.

On the 6th of May, 1883, an eclipse occurred, total for more than five minutes where it was central; but, unfortunately, its line passed over the Southern Pacific Ocean, and the only available place from which to observe it was a coral reef named Caroline Island, about 7½ miles long by 1½ mile wide. It is near the Marquesas group, and its existence had only been known since 1874. Nevertheless, astronomers were not to be balked of their opportunity, and as the weather fortunately admitted of it, some valuable observations were made, though chiefly confirmatory of those previously obtained; whilst a fruitless search was made for a supposed planet within the orbit of Mercury. The corona was identical in appearance with that of 1882; and the sun-spot maximum of that year, it

will be remembered, was exceptionally protracted.

An eclipse was total in New Zealand on the 9th of September, 1885, but no observations of any importance were made on that occasion, so that we must pass on to the year 1886, when an eclipse, on the 29th of August, was total during about four minutes, at Grenada, in the West Indies, and the adjacent parts of South America, though the greatest length of totality (more than six and a half minutes) was unfortunately in the middle of the Atlantic Ocean. English, Italian and American astronomers repaired to Grenada and its neighbourhood. They were, on the whole, by no means favoured by the weather; but some good results were obtained, Prof. Tacchini in particular calling attention to very elevated developments of protuberances of a kind which cannot be manifested by the spectroscope under ordinary circumstances without an eclipse. The corona, as photographed by Dr. Schuster and Mr. Maunder, was of what may be called an intermediate type.

An eclipse which occurred on the 19th of August, 1887, was a great disappointment on account of the cloudiness of the skies over the

greatest part of its track. This passed from Berlin (where the Sun rose eclipsed) in an easterly direction through Russia and Siberia, and then south-easterly to Japan. Here and there a few photographs of the corona were caught between clouds, but on the whole the occasion proved a failure for any important work. Prof. Todd went to Japan, where, as in many other places, nothing could be seen of the phenomenon. The Russian professor Mendeleef ascended in a balloon to the height of more than two miles, and had a fine view of the corona, but could not, under the circumstances of his position, obtain scientific results.

The year 1888 had no total eclipses, but 1889 furnished two, the first of these being on New Year's Day. The shadow path was but narrow, and the duration of totality in California amounted to less than two minutes. Weather was, however, favourable, and a large number of excellent photographic records were taken. The occasion was one of solar spot minimum, and it was found that the structure of the corona was of the so-called "winged" type, and the streamers were noted to extend approximately in the direction of the ecliptic. But it was felt that the outermost

parts of the corona should be photographed, and it was hoped that an opportunity might be obtained on the occasion of the second total eclipse of that year, which occurred on the 22nd of December. The scenes of operations were this time to be the northern coast of South America, and the west coast of Africa, the shadow passing across the Atlantic Ocean in a nearly easterly direction. But disappointment was again the order of the day. Some observations indeed were obtained, but they were taken through misty air; and the most remarkable event of the eclipse was a very sad one. Father Perry, of Stonyhurst College, who had taken part in many scientific expeditions, went on this occasion to the Salut Islands, off Cayenne, in French Guiana. Stricken with malaria, he managed to take a few photographs of the eclipse, and died at sea only five days afterwards.

The next total eclipse occurred on the 16th April, 1893. The line of totality passed from Chili to Cape Verde; the weather was fine, and both in South America and West Africa (especially the former) valuable results were achieved. It is impossible to furnish, in our short space, even a brief, much less an adequate, account of these; but we give some of

the remarks made by Prof. Pickering, of Harvard College, who was located at Minasaris in Chili, and speaks of the atmospheric conditions there as perfect. As regards the form of the corona, he says the observations indicated a state of great disturbance. Four streamers were seen proceeding from the corona, two of which stretched over a distance of more than 435,000 miles. Dark rifts were also visible, extending directly westward from the Moon's limb to the utmost limit of the corona. Several solar prominences attained great distinctness and brilliancy, some reaching to a height of 80,000 miles. These were well photographed. The corona showed a conical structure, with a network of fine filaments visible to the naked eye. Comparison of photographs taken at different places showed the presence and motion of a comet in the interior part of the corona. On the whole, the observations of this eclipse showed that though some streamers were seen, the corona generally exhibited that uniform distribution characteristic of eclipses occurring at times of maximum sun-spot activity.

In 1894 an eclipse of the Sun on the 29th of September was total, but only for a very short time, over part of the Indian Ocean, so

that no attempt was made to observe it. But great expectations were formed with regard to one which occurred on the 9th of August, 1896, expeditions being organised to observe it in Norwegian Lapland, and in Yezo, the northern island of Japan. At the former locality the duration of totality amounted to less than two minutes; at the latter to about two and a half minutes; and in south-eastern Siberia to nearly three minutes. But bad weather prevailed at nearly all the stations, excepting at Novaya Zemlya, whither Sir George Baden Powell had conveyed a party in a private yacht. This included the late Mr. Stone, then Radcliffe Observer at Oxford, and Mr. Shackleton, of South Kensington, who obtained some good observations and photographs of the corona, which was found to be of an intermediate type, presenting a striking resemblance to that of the eclipse in 1886, about ten years before. The next total eclipse of the Sun took place on the 22nd of January, 1898, the shadow of which passed from Central Africa across the ocean to the south of Arabia into India. Parties of astronomers spread themselves from the neighbourhood of Bombay to that of Benares, and, being favoured by fine weather, made extensive and valuable observations. The corona

presented a striking resemblance to that of the Indian eclipse of 1868, which was as long (about two years) after a minimum of sun-spots as the eclipse in question was before one.

The great scientific interest of eclipses, especially of total eclipses, of the Sun, will be evident from what has preceded. The same cannot be said of Lunar eclipses; but our plan requires that a few words should be devoted to them and to the bearing of some of those observed in ancient times upon chronological questions.

An eclipse of the Moon is in many respects a different phenomenon from one of the Sun. For whereas the Moon's shadow sometimes does not reach the Earth, and when, from her greater proximity, it does reach our globe, it can at most cover only a zone of about 170 miles in diameter, and the duration of totality of an eclipse of the Sun can never exceed eight minutes. But the Earth's shadow extends far beyond the distance of the Moon, and when the latter is centrally eclipsed, the complete obscuration exceeds an hour and a half, and may last as much as an hour and fifty minutes. We say complete obscuration; but even when wholly involved in the Earth's shadow, the Moon is generally visible, of a red or coppery hue. This effect is due to the refraction of the Earth's

atmosphere, and varies much in intensity, according to the amount of vapour contained in the parts of the atmosphere through which the solar rays pass at the time. The eclipse of the 19th of March, 1848, was remarkable for the distinctness with which the Moon was seen throughout, and the deepness of the red colour. On the other hand, during the eclipses of May 18, 1761, and June 10, 1816, the Moon became completely invisible. And cases have occurred in which part of the Moon has continued visible during totality, while the rest has been wholly obscured. The difference, of course, has to do with the Earth's atmosphere, and the conditions of certain parts of it, but not at all with the Moon.

The earliest Lunar eclipses of which we have any trustworthy account are three copied by Ptolemy from Chaldæan records. They were observed at Babylon on dates corresponding in our chronology to the 19th of March, B.C. 721, and the 8th of March and the 1st of September, B.C. 720, during the reign of a king whom Ptolemy calls Mardokempados, but whose Chaldæan name was Merodach-Baladan, and who carried on a long contest with Sargon, the great king of Assyria, which ended in the complete success of the latter and the subjection of Babylon to the rule of

the Ninevite kings. Of these three eclipses, the first only was total. Ptolemy also reports a partial lunar eclipse, observed at Babylon in the fifth year of the reign of Nabopolassar (who, in conjunction with Cyaxares, had taken and destroyed Nineveh), which is calculated to have occurred on the 22nd of April, B.C. 621; and three other partial eclipses, in the seventh year of the reign of Cambyses, king of Persia, and the twentieth and thirty-first years of Darius, the son of Hystaspes, the dates of which were July 16, B.C. 523, Nov. 19, B.C. 502, and April 25, B.C. 491, the last being the year preceding the battle of Marathon.

A total eclipse of the Moon, mentioned by Aristophanes in 'The Clouds,' was observed at Athens on the 9th of October, B.C. 425; and one which fell on the 27th of August, B.C. 413, so frightened Nicias, general of the Athenian army in Sicily, that it caused the delay in his retreat from Syracuse which led to the destruction of his whole army. Xenophon speaks of a total one which occurred in the twenty-sixth year of the Peloponnesian War (that of the sea-fight at Arginusæ, in which Callicratidas, the Spartan commander, was killed), and was evidently that of the 15th of April, B.C. 406.

Ptolemy reports two other Babylonian

eclipses (both partial), observed on dates corresponding to Dec. 23, B.C. 383, and June 18, B.C. 382. A small one also occurred on the 9th of August, B.C. 357, whilst Dion was setting out to attack Dionysius, tyrant of Syracuse.* After this, the most noteworthy lunar eclipse took place on the night of the 20th of September, B.C. 331, eleven days before the decisive victory of Alexander the Great over Darius at Arbela, or rather, at Gaugamela.

Polybius mentions a total eclipse of the Moon seen in Asia Minor on a date corresponding to the 1st of September, B.C. 218, which so alarmed some Gaulish mercenaries in the service of Attalus I., king of Pergamum, that they refused to advance any farther. This, it will be remembered, was about the time that Hannibal was making his famous passage over the Alps into Italy.

We owe to Ptolemy a notice of four which were observed at Alexandria during the rule of the Ptolemies: two total in the same year, on the 19th of March and the 12th of September, B.C. 200; and two partial on dates corresponding to Sept. 22, B.C. 201, and May 1,

* According to Plutarch, Dion himself understood the cause, but it somewhat alarmed his men, until the diviner declared it to be a good omen.

B.C. 174. These are not connected with any historical events; but one which occurred on the 3rd of September, B.C. 168, was on the night preceding the victory of Pydna, gained by Paulus Æmilius over Perseus, the last king of Macedon.

We shall only refer to one later lunar eclipse, on account of its importance; that stated by Josephus to have occurred during the last illness of Herod the Great. A consideration of all the circumstances shows that this must have been the partial eclipse on the night of the 12th of March, B.C. 4, and therefore proves that the birth of Christ took place towards the end of the preceding year, B.C. 5.

A total eclipse of the Moon is due this year (1898), on the 27th of December, and another on the 23rd of June next year (1899); this former will be visible in this country, the latter will not. There will be no total eclipse of the Sun until 1900.

The principal point to which attention is to be directed in future solar eclipses, and further information sought, is the nature of the outer part of the corona. Though an appendage of the Sun, it cannot be a solar atmosphere in the sense in which our atmosphere is of the Earth. It is a mass of matter in the interior

of the solar system, portions of which are in a perpetual state of influx to, and efflux from, the Sun. Much is yet to be learnt respecting its composition, and it is yet hoped that means may be found for studying it, like the protuberances, without waiting for the rare occasion of a total solar eclipse. One thing is quite certain—the matter composing it must be of very great tenuity, for comets frequently pass through it without suffering sensible retardation.

In conclusion, it may be mentioned that the next total solar eclipse will take place on the 28th of May, 1900; the central line of this will pass across Portugal, Spain, and Algeria, so that European astronomers need not travel far for its observation. Its duration will nowhere much exceed two minutes; but the totality of one which will pass over Sumatra and Borneo on the 17th of May, 1901, will last in some places for six and a half minutes.

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